Fractured Reservoir Modeling: Coupled Seismic and Fluid Response

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RESEARCH OBJECTIVES

Fractured reservoirs are more difficult to model and typically less well understood than porous reservoirs. These problems lead to greater expense in resource exploration/exploitation and in environmental characterization and cleanup. We are coupling state-of-the-art fractured-media modeling codes to allow investigation of the seismic response to fluid-induced changes in reservoir properties, such as pore pressure and permeability. This research could lead to improvements in remote sensing and time-lapse monitoring of dynamic processes in fractured reservoirs.

APPROACH

We have coupled two previously independent modeling codes, a hydromechanical finite-element code and a 3-D seismic finite-difference, elastic, anisotropic modeling code. In both codes, fractures are defined by their mechanical stiffness, which is in turn linked to permeability and seismic response by recently developed theoretical relationships. Using the hydromechanical code, we simulate injecting fluid into or withdrawing fluid from a reservoir for a length of time. This creates fluid-pressure gradients that act to change the fracture stiffness. Conceptually, the spatially variable fluid pressure causes fractures to open or close inhomogeneously. In a dynamic process, as fracture stiffness changes, fracture permeability and fluid pressure distribution change, which then influence the next change in fracture stiffness.

At any given time, we can apply spatially variable fracture-stiffness values to model the seismic response of the reservoir. These stiffness values are used to calculate anisotropic elastic constants, which control seismic wave propagation. In general, the reservoir has a unique set of elastic constants for each finite-element cell or finite-difference grid point. The seismic response of the reservoir can be used to spatially map the variations in elastic constants, which can then be related to variations in fracture stiffness and, in turn, to pore-pressure and permeability variations in the reservoir. In this manner, time-lapse seismic surveys can monitor reservoir changes.

ACCOMPLISHMENTS

We have successfully coupled the hydromechanical and wave-propagation modeling codes. The initial study considered a 3-D vertically fractured reservoir layer sandwiched between two homogeneous, relatively impermeable nonfractured layers. The layer is assumed to have a single dominant fracture direction. For two months, fluid is injected into the center of the reservoir via a vertical well at 80 liters per minute over the 60 m thick reservoir. A 3-D, three-component surface seismic survey was modeled at various times. Figure 1 shows the response at pre-injection (left) and at 2 months post-injection (right). A distinct change is seen in reservoir seismic reflectivity. This change is most evident in the amplitude and time of a P- to S-wave converted reflection polarized normal to the fractures. This change in seismic response is caused by the fluid injection changing fracture stiffness.

SIGNIFICANCE OF FINDINGS

Understanding fractured reservoirs is important for many problems facing the U.S. Department of Energy (and the U.S. in general), including resource development (oil and gas production), underg round storage of high-level waste, remediation of contaminated aquifers, geologic sequestration of CO_2, and groundwater exploration and storage. Currently, fluid flow modeling and seismic imaging are considered separately. Linking these fields through a consistent conceptual and theoretical framework will allow improved understanding of coupled processes, and may lead to improved monitoring of reservoir conditions.

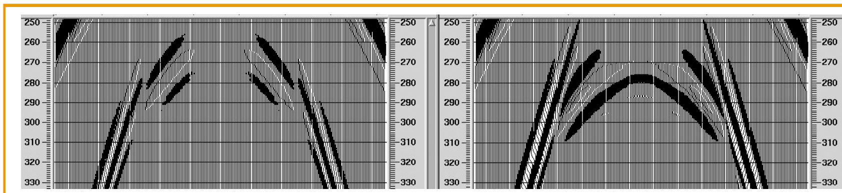

Figure 1. Surface seismic shot gather for the three-layer model described in the text. Pre-injection (left) and post-injection (right) comparison shows a substantial change in the event between 270 and 310 ms. This change in seismic reflection response is caused by fluid pressure changes in the reservoir due to injection.

RELATED PUBLICATION

Schoenberg, M., K. Nihei, T. Daley, J. Rutqvist, and E.L. Majer, Fractured reservoirs: An analysis of coupled elasto-dynamic and permeability changes due to pore pressure variation. Presented at the Society of Exploration Geophysicists' Pore Pressure Workshop, May 2002; Berkeley Lab Report LBNL-50697, 2002.

ACKNOWLEDGMENTS

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